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NUCLEAR CRITICALITY SAFETY EVALUATION
FOR THE REMOTE-HANDLED WASTE FACILITY

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NUCLEAR CRITICALITY SAFETY EVALUATION
FOR THE REMOTE-HANDLED WASTE FACILITY

1.0 INTRODUCTION

This nuclear criticality safety evaluation (NCSE) provides the criticality and contingency analyses that have been performed to support safe operations in the Remote Handled Waste Facility (RHWF) at the West Valley Demonstration Project (WVDP). The purpose of the RHWF is to size reduce (i.e., cut up), radiologically analyze, and repackage into appropriate (standard) types of waste containers various radioactive waste forms. Limited decontamination of waste items with water may be performed. Decontamination of waste items with high pressure nitrogen may also be performed.

The revisions and/or dates associated with the documents cited in this NCSE are provided in Section 9.0. The versions cited in Section 9.0 are the versions that were reviewed during the development of this NCSE. It is considered highly unlikely that later version(s) of these documents would invalidate the fundamental analyses and conclusions contained in this NCSE. Therefore, later version(s) of the documents cited in Section 9.0 can be and should be used as they become available, unless prohibited (e.g., DOE Order 420.1A, *Facility Safety*, prescribes the revision to use for certain ANSI/ANS nuclear criticality safety standards).

2.0 DESCRIPTION

Table 1 lists the waste streams to be processed in the RHWF. Waste streams 12 through 16 encompass the 22 boxes of components and debris that were generated as the result of the disassembly and removal of various components from the Chemical Process Cell (CPC). The CPC was used to dissolve spent nuclear fuel. Hence, CPC components are generally expected to be contaminated with a distribution of radionuclides that is consistent with the distribution of radionuclides that is found in spent nuclear fuel. WVNS-SAR-001, *Safety Analysis Report for Waste Processing and Support Activities*, Table 7.7-4, shows an estimated 490.81 grams (U-235 equivalent) are contained in waste streams 12 through 16. Table 7.7-4 of WVNS-SAR-001 also provides an estimate of the Cs-137 activity in each of the subject 22 boxes. The total Cs-137 activity shown in Table 7.7-4 is 274.29 curies. As presented in Section 6.0 of this document, the 274.29 curies of Cs-137 estimated to be contained in the 22 boxes provide the basis for calculating a fissile material inventory of 461 grams. For reasons presented below, the other waste streams are considered to contain substantially less fissile material than that estimated for the subject 22 boxes.

Waste streams 17 and 18 are predominantly, if not entirely, filters from ventilation system(s) that service areas and cells in the Main Plant. Waste streams 20 and 22 have similar content, namely items from various projects associated mostly with the Main Plant. These items include anti-contamination clothing and other personnel protective equipment, plastic, wood, metal, hoses, tools, rope, piping, and solid debris. Waste stream 21 contains diatomaceous earth, clay absorbent, and a relatively small amount of Zeolon 100 used for the filtering of pool water in the Fuel Receiving and Storage (FRS) facility. Waste stream 24 consists of crane components from the Main

Plant. In consideration of their service/function and/or measured dose rates, the items associated with these waste streams, i.e., waste streams 17, 18, 20, 21, 22, and 24, are considered to have a limited fissile material inventory relative to the fissile material inventory in the 22 boxes previously discussed. (With certain assumptions, measured dose rates can be used to estimate fissile material inventory. It is understood that in some instances, the measured dose rates are being affected by shielding materials inside the boxes and drums.) The very modest radiological material inventory that is expected to be associated with waste stream 19 is addressed in WVNS-SAR-022, *Safety Analysis Report for the Chemical Process Cell - Waste Storage Area*, Rev. 0, Draft G, which has been archived. Section 7.3.1 of WVNS-SAR-022 states the following regarding waste stream 19: “The thirteen waste storage boxes placed outside the shield modules were packaged in late 1984 and early 1985 and contain contaminated items: a monorail crane leg, analytical sludge samples, vessels, manipulators, beams, glove boxes, and general contaminated waste.” Table 7-3 of WVNS-SAR-022 shows that the 13 boxes are estimated to contain a total of 1.2 curies of Cs-137, and a fissile mass (U-235 equivalent) of 2.15 grams. Waste stream 23 consists of Waste Tank Farm (WTF) pumps. For reasons provided in Section 6.0, the WTF pumps do not present a significant source of fissile material.

It is estimated that over 90% of the waste to be repackaged in the RHWF will be classified as low-level waste. Only a small percentage will be classified as transuranic (TRU) waste, which is defined as “radioactive waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years.” From this definition, designation of waste as transuranic provides essentially no insight as to potential criticality concerns.

2.1 Characteristics of Spent Nuclear Fuel at the WVDP

WVDP-EIS-014, *Characterization of Reactor Fuel Reprocessed at West Valley*, provides detailed physical and radiological characteristics of the nuclear fuel that was reprocessed by Nuclear Fuel Services (NFS). During operations from 1966 to 1972, NFS reprocessed approximately 640 metric tons of nuclear fuel. There were a total of 27 reprocessing campaigns during this period; however, only the first 26 campaigns reprocessed intact reactor fuel. The last campaign involved processing a liquid uranium/plutonium solution.

Fuel initially reprocessed by NFS was received from the New Production Reactor at Hanford due to an insufficient backlog of fuel at commercial nuclear facilities. Fuel received from this reactor, which ultimately accounted for over half of the total mass reprocessed by NFS, had an initial U-235 enrichment between 0.71 and 1.0 weight percent. The majority of the balance of fuel reprocessed by NFS (approximately 38% of the total by mass) had an initial U-235 enrichment less than 4.0 weight percent. Only 2.5% of the fuel reprocessed by NFS had an initial U-235 enrichment greater than 5.0 weight percent and no fuel had an initial U-235 enrichment higher than 5.83 weight percent.

Initial U-235 enrichments misrepresent the actual reactivity of fuel received by NFS, however, as historical records indicate that most of the higher initially enriched commercial fuel was irradiated through reactor operation, thereby significantly decreasing the inventory of U-235 present in the fuel. When burnup of this commercial fuel is accounted for, it is found that only about 5% of post-irradiated fuel had an effective U-235 enrichment greater than 3 weight percent, and with only one exception, none of the post-irradiated fuel had an effective U-235 enrichment greater than 4 weight percent. Fuel associated with Campaign number 11, which was comprised of a thorium-uranium fuel in an approximately 15 to 1 ratio of thorium to uranium, is the one exception. The U-233 plus U-235 equivalent enrichment of the thorium-uranium fuel after irradiation was approximately 6.39 weight percent. Hence, 2.5% of the fuel reprocessed by NFS had an effective U-235 enrichment of about 6.39 weight percent, while the rest had a maximum effective U-235 enrichment of 3.327 weight percent.

In consideration of the information presented above, it would be an extremely conservative assumption to assume that spent nuclear fuel in the CPC components and debris stored in the 22 boxes addressed above has a U-235 enrichment of 5 weight percent. It is noted that ANSI/ANS-8.1-1983, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, Table 3, shows a U-235 enrichment single parameter limit for a metal unit of 5.0 weight percent. To further assure the extremely conservative nature of such an assumption, historical records were reviewed to determine whether there is any basis for believing that a disproportionate amount of fuel from Campaign 11 (i.e., the campaign associated with the thorium/uranium mixed oxide fuel) exists in the CPC components and debris stored in the 22 boxes addressed above. Specifically, the eleventh and twelfth NFS Quarterly Reports were reviewed. These Quarterly Reports address the time period between October 1, 1968, and March 31, 1969, and include information on Campaign 11.

The processing of Campaign 11 involved fuel with a higher enrichment than any previously processed by NFS. Consequently, “significant preparation and checkout of processing and waste storage facilities were performed.” The only unplanned shutdowns associated with mechanical operations during the quarter starting October 1, 1968 involved (1) replacement of a dissolver off-gas blower, (2) awaiting approval from the applicable governmental entity to process Campaign number 11 fuel, and (3) repair of the GPC crane. The Quarterly Report for the quarter starting January 1, 1969 states that a “thorough flushout of the processing plant” was required between Campaign 11 and Campaign 12 since less than 5 grams of Campaign 11 uranium processed would cause tons of Campaign 12 uranium to be out of specification, and that no significant malfunctions of plant equipment occurred during this reporting period.

The information from the Quarterly Reports indicates that “extra measures” were taken to prepare for the processing of Campaign 11 fuel, as well as upon the completion of Campaign 11. These extra measures apparently included waste removal and cleanup activities beyond the norm for a campaign. There were no significant or important mechanical equipment malfunctions during Campaign 11. Campaign 11 was followed by 15 more campaigns involving intact reactor fuel. Waste removal, cleanup, and limited decontamination efforts associated with each of these campaigns and post-reprocessing activities would have contributed to the removal of any mixed oxide fuel remaining from Campaign 11. In consideration of these facts, there is no basis for believing that a disproportionate amount of spent nuclear fuel from Campaign 11 exists in the CPC components and debris stored in the 22 boxes addressed above.

3.0 REQUIREMENTS DOCUMENTATION

There are no requirements that are unique to this evaluation. This NCSE has been developed in accordance with WVDP-162, *WVDP Nuclear Criticality Safety Program Manual*.

4.0 METHODOLOGY

As discussed in Section 2.0, waste streams 12 through 16 are considered to present the largest source of fissile material. The calculations that provide the basis for estimating the fissile material contained in waste streams 12 through 16 were performed with the ORIGEN-ARP and ORIGEN-S modules of Standardized Computer Analyses for Licensing Evaluation (SCALE), version 4.4a. EM-125, *Verification, Validation and Control of Computer Software*, has been implemented in association with the subject codes. SCALE 4.4a is a computer code system for criticality, shielding, and thermal analysis of nuclear facility and package designs. The system was initially developed from 1976 to 1980 at Oak Ridge National Laboratory (ORNL) for the Nuclear Regulatory Commission (NRC). The system is currently maintained and enhanced under the co-sponsorship of the NRC and Department of Energy (DOE). SCALE 4.4a has been licensed by the Radiation Safety Information Computational Center (RSICC) located in Oak Ridge, Tennessee to select URS office locations.

SCALE 4.4a contains numerous control and functional modules. Only ORIGEN-ARP and ORIGEN-S were used to support the analyses contained herein. ORIGEN-S computes time dependent concentrations and source terms of a large number of isotopes, which are simultaneously generated or depleted through neutronic transmutation, fission, radioactive decay, input feed rates, and physical or chemical removal rates. The matrix exponential expansion model of the ORIGEN code is unaltered in ORIGEN-S. Essentially all features of ORIGEN have been retained, expanded, or supplemented with ORIGEN-S. (The “-S” denotes that this is the version of ORIGEN that has been incorporated into the SCALE software system.) The following is from the July 2001 edition of the *SCALE Newsletter*.

> ORIGEN-ARP is an automated system to perform isotopic depletion/decay calculations using the ARP (Automated Rapid Processing) and ORIGEN-S codes of the SCALE system. The package includes the OrigenArp Windows graphical user interface (GUI) that prepares input for ARP and ORIGEN-S. ARP automatically interpolates cross sections for the ORIGEN-S depletion analysis using enrichment, burnup, and optionally moderator density, from libraries generated with the SCALE SAS2 depletion sequence. Library sets for four LWR fuel assembly designs (BWR 8x8, PWR 14x14, 15x15, 17x17) are included. The libraries span enrichments from

1.5 to 5 wt % U-235 and burnups of 0 to 60,000 MWD/MTU. Other libraries (e.g., DLC-210 for CANDU fuel) are available from RSICC. SCALE users can generate their own libraries for other fuel assembly designs using the tools in SCALE 4.4a. The interpolated cross sections from ARP are passed to ORIGEN-S to perform the depletion/decay calculations.

Subcritical limits from ANSI/ANS-8.1-1983, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, are used to establish that all processes/operations associated with the RHWF will remain subcritical under all normal and credible abnormal and accident conditions.

5.0 DISCUSSION OF CONTINGENCIES

DOE-STD-3007-93, *Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Non-Reactor Nuclear Facilities*, states the following regarding Section 5.0 of an NCSE: “Compliance with the double contingency principle, as stated in DOE Order 5480.24 and DOE O 420.1, Section 4.3, and the requirements of Section 4.1.2 of ANS-8.1 should be demonstrated in this section. This may be done by several different methods.” Regarding Section 5.0 of an NCSE, DOE-STD-3007-93 also states the following: “Some systems will remain subcritical during any combination of credible upset conditions. For such systems, simply state the fact in this section.” Demonstration that the double contingency principle has been satisfied does not necessarily mean that a criticality event is not credible since a contingency is “a possible but unlikely change in a condition/control important to the nuclear criticality safety of a fissionable material operation that would, if it occurred, reduce the number of barriers (either administrative or physical) that are intended to prevent an accidental nuclear criticality.” Nevertheless, the analyses presented in this NCSE are considered to demonstrate that for the waste streams proposed to be processed through the RHWF, it is not credible for a criticality event to occur during normal operations or because of credible accident scenarios. An inadvertent criticality event is not credible because (1) there is a very limited amount of fissile material estimated to be present in the waste streams (i.e., an amount less than the single parameter limit of 760 grams of U-235 for a uniform aqueous solution per ANSI/ANS-8.1-1983); (2) the fissile material is distributed through a very large volume and mass of waste materials, only a small percentage of which will be in the RHWF at any given time; (3) the fissile material in the waste streams is by-and-large physically and/or chemically fixed/bound to the items that comprise the waste streams; and (4) there are no normal operations or credible accidents that are considered to have the potential to redistribute (and aggregate) a significant amount of the fissile material, especially in a (water) moderated environment. All areas in the RHWF where fissile materials could be present will remain subcritical under all normal and credible abnormal and accident conditions. There are no design features that are relied upon to ensure criticality safety in the RHWF. Though some of the structures, systems, and components (SSCs) in the RHWF may have been designed with consideration for preventing a criticality event, this NCSE establishes that no passive or active SSCs are required to ensure that a criticality event in the RHWF is not a credible event.

A double contingency analysis for the RHWF is presented in Table 2. For operations not related to repackaging, the analysis indicates that substantial changes in either (1) the estimated fissile mass to be processed through the RHWF, or (2) the form/distribution of fissile material (and hence concentration and geometry) would need to occur for the double contingency principle to be violated. Moderation is not addressed as a contingency for normal operations and accidents not related to repackaging since no credit for preventing a criticality has been taken for design features of SSCs (e.g., the Work Cell trench, drain hub, wash down receiving tank, and ion exchange column(s) which are discussed in Section 6.0). For repackaging operations, which will be performed in accordance with established documents that support criticality safety, human and/or instrument induced error(s) resulting in excessive (i.e., not allowed) fissile mass being placed in waste container(s), or the inadvertent introduction of significant quantities of moderator (water) into waste container(s), would need to occur for the double contingency principle to be violated. Additionally, a favorable/suitable geometry would (inadvertently) need to have been created within the waste container.

6.0 EVALUATION AND RESULTS

As previously stated, the purpose of the RHWF is to size reduce (i.e., cut up), radiologically analyze, and repackage into appropriate (standard) types of waste containers various radioactive waste forms. Limited decontamination of waste items with water may be performed. Decontamination of waste items with high pressure nitrogen may also be performed.

6.1 Fissile Mass Estimates

Waste streams 12 through 16 encompass the 22 boxes of components and debris that were generated as the result of the disassembly and removal of various components from the CPC. Table 7.7-4 of WVNS-SAR-001 shows an estimated 490.81 grams (U-235 equivalent) are contained in these waste streams. As previously stated, the CPC was used to dissolve spent nuclear fuel. Hence, CPC components are generally expected to be contaminated with a distribution of radionuclides that is consistent with the distribution of radionuclides that is found in spent nuclear fuel. Exceptions to this expectation may exist, particularly in hardened sludge deposits, which are apparently limited as documented below. It is noted that DOE/NE/44139-41, *Decontamination and Decommissioning of the Chemical Process Cell*, Section 4.3, which addresses “sampling of floor debris,” states “isotope ratios indicated that the debris were primarily spent fuel in nature.” *Decontamination and Decommissioning of the Chemical Process Cell* also states the following regarding “preparations for vessel removal:” “After steam cleaning, the vessels received a clear fixative coating, the vessel internals were inspected using a crane suspended video camera, vessel heel dewatering was performed if needed with an air operated jet, and all cooling water nozzles were sealed with rubber plugs. Vessel inspections showed most vessels to be relatively clean inside. The exceptions were the recycle evaporator and the low level waste accountability tank.” Each of these two vessels removed from the CPC have an approximate one inch layer of “dried, caked debris” on the bottom, as documented in Section 7.2.3 of WVNS-SAR-022 (which has been archived). This “dried, caked debris” on the bottom of each vessel has not been characterized. Originally, about a foot of sludge existed on the bottom of these vessels. “The sludge was mobilized and pumped dry and air was blown in; an approximate 1-inch layer of dried, caked debris remained on the bottom of each vessel.” Hence, the form of this one inch of material renders it very unlikely that routine operations or credible accident phenomena could reconfigure it into a critically favorable geometric shape in a (water) moderated environment. Additionally, the fissile mass estimates (provided in WVNS-SAR-001 and below) are considered to be conservative, and hence may envelope the fissile material inventory in the one inch layers.

Another approach was undertaken to estimate the amount of fissile material in waste streams 12 through 16. WVNS-SAR-001, Table 7.7-4, provides an estimate of the Cs-137 activity in each of the boxes associated with these waste streams. With the exception of one box, the basis for Table 7.7-4 is Memo HB:86:0161. Memo HB:86:0028, which predates Memo HB:86:0161, provides much of the information contained in Memo HB:86:0161. Memo HB:86:0028 shows that the Cs-137 activity estimates reflected in Table 7.7-4 had been made for 17 of the 22 boxes that comprise waste streams 12 through 16 by February 18, 1986. With the exception of one of the 22 boxes, Cs-137 estimates for the other (four) boxes were established by November 5, 1986, as is documented in Memo HB:86:0161. In consideration of this information, to establish a “proper” time period for decay of the Cs-137, the 274.29 curies of Cs-137 shown in Table 7.7-4 was assumed to exist as of July 1, 1986. The ORIGEN-ARP generated input file and pertinent portion of ORIGEN-S output file for decaying 274.29 curies of Cs-137 for 6.75 years are provided in Table 3 and Table 4, respectively. (The actual time period for decay was 6.75 years as can be seen in the input file on line “60**.” The output file shows a rounded value of 6.8 years.) A radionuclide distribution (corrected to the year 1993) for the spent nuclear fuel processed at West Valley is provided in Attachment 1 of *Estimation of Activity in the Former Nuclear Fuel Services Reprocessing Plant*, dated March 1993. Hence, the decay period of 6.75 years corresponds to the time from July 1, 1986 to April 1, 1993. The decay corrected value, 235 curies of Cs-137, was divided by the Cs-137 activity shown in Attachment 1 of *Estimation of Activity in the Former Nuclear Fuel Services Reprocessing Plant*, and that value was multiplied by the activity given for the other 51 radionuclides listed in Attachment 1 of *Estimation of Activity in the Former Nuclear Fuel Services Reprocessing Plant*. The results of this effort are shown in Table 5. The values shown in Table 5 were decayed 11.25 years, which corresponds to the time from April 1, 1993 to July 1, 2004. The ORIGEN-ARP generated input file and pertinent portion of the ORIGEN-S output file for decaying activity in the 22 boxes for 11.25 years are provided in Table 6 and Table 7, respectively. (ORIGEN-ARP can only accommodate 50 nuclides per input file. Attachment 1 of *Estimation of Activity in the Former Nuclear Fuel Services Reprocessing Plant* lists 52 spent nuclear fuel-related radionuclides. C-14 and Fe-55 were the two radionuclides that were excluded from the input file shown in Table 6. No attempt was made to purge from the input file other radionuclides that do not contribute to the fissile mass as the input file was originally generated for purposes other than supporting this NCSE.) The “11.3 yr” column of the ORIGEN-S output shown in Table 7 provides the quantity of actinides associated with waste streams 12 through 16. (The actual time period for decay was 11.25 years as can be seen in the input file on line "60**." The output file shows rounded values.) The total mass of actinides shown in the "11.3 yr" column of Table 7 is 2.17E+04 grams. Subtracting from this amount the 2.12E+04 grams of U-238 (a non-fissile radionuclide) yields 500 grams of actinides. Of this 500 grams, 78.6% is U-235, 10.3% is Pu-239, 1.7% is U-233, and 7.8% is U-236 (which is not a fissile radionuclide). Subtracting the 39 grams of U-236 from the 500 grams noted, and conservatively assuming the other actinides shown in Table 7 are fissile, yields 461 grams of fissile material, with the vast majority constituted as U-235. It is noted that nearly all of the actinides have relatively long half-lives. As can be seen in Table 7, the total mass of actinides does not change over 11.25 years. Hence, a few months change in the RHWF startup date has an insignificant impact on fissile mass estimates. More specifically, starting RHWF operations a few months before July 1, 2004 (e.g., in March 2004 or April 2004) has a negligible impact on fissile mass estimates.

The Cs-137 activity estimates in Table 7.7-4 of WVNS-SAR-001 reflect an assumption that for each curie of Cs-137, a dose rate of 80 mR/hr exists. Section 7.2.1 of WVNS-SAR-022 states "In a memo updating the fissile content (Meigs and Keel 1986), a factor of 80 mR/hr per curie for Cs-137 was used, assuming measurements were made at about 3 inches from the surface of the waste box." *Decontamination and Decommissioning of the Chemical Process Cell* documents that 12 of the boxes of waste that came from the CPC are 1.8 m x 1.8 m x 3.6 m. Three MicroShield 5.05 cases were developed that provide a measure of assurance that the assumption of 80 mR/hr for each curie of Cs-137 is an adequate, and possibly conservative, assumption. One case modeled 0.946 curies of Ba-137m uniformly distributed in air in a rectangular volume with the box dimensions noted. (In equilibrium, for each curie of Cs-137, a beta particle emitter, there exists 0.946 curies of Ba-137m, a gamma ray emitter.) This case showed that iron box walls would need to have a thickness of 0.915 inches to obtain a dose rate of 80 mR/hr at a distance of 3 inches from the midpoint of the box. (Carbon steel is about 99 wt% iron and 1 wt% carbon. WVNS-SAR-022 indicates that the boxes are made of carbon steel.) Another case modeled 0.946 curies of Ba-137m as a 1.8 m line source up against the box inner wall. (A line source is used to represent a jumper or non-jumper piping section, since several of the boxes contain this type of waste.) In this instance, the iron box wall would need to have a thickness of 3.26 inches to obtain a dose rate of 80 mR/hr at a distance of 3 inches. Another case modeled 0.946 curies of Ba-137m as a 1.8 m line source in the middle of the box (i.e., 0.9 m from the box inner wall). In this instance, the iron box wall would need to have a thickness of 1.52 inches to obtain a dose rate of 80 mR/hr at a distance of 3 inches. It is acknowledged that these are simplistic models of complex radiation shielding problems. Nevertheless, they are considered to provide meaningful insight for evaluating the adequacy of the 80 mR/hr per curie of Cs-137 assumption. Lastly regarding this topic, it is noted that Chapter 7 of WVNS-SAR-022 documents other configurations used to model the contents of the 22 boxes. For most of the boxes, the results showed dose rates approximately 50% or more higher than the 80 mR/hr per curie of Cs-137 noted above. A dose rate of less than 80 mR/hr per curie of Cs-137 was calculated for only two boxes. Consequently, the calculations documented in Chapter 7 of WVNS-SAR-022 yield a total Cs-137 activity estimate of 215.20 curies, as compared to the 274.29 curies that were used as the basis to estimate the amount of fissile material.

Section 2.0 discusses waste streams 17 through 24, which are listed in Table 1. By virtue of their service/function and/or measured dose rates, these waste streams are not considered to present a significant source of fissile material. Additionally, any fissile material in these waste streams is by-and-large physically and/or chemically fixed/bound to the items that comprise the waste streams. Consequently, there are no normal operations or credible accidents that are considered to have the potential to redistribute (and aggregate) a significant amount of the limited fissile material associated with these waste streams.

Waste stream 23 consists of Waste Tank Farm (WTF) pumps and mechanical arms used in the WTF. WVNS-SD-055, *System Description Sludge Mobilization System HLW Transfer System*, Section 1.2.3.6, which addresses “sludge and zeolite mobilization pumps,” states the following:

> Each pump is supported from a 50 foot long stainless steel pipe column 14 inches in diameter. These columns house the pump drive shaft. Each column is filled with water to lubricate the shaft bearings and to provide radiation shielding. The column of water puts static pressure on its lower seal to inhibit the tank contents from entering the pump columns.

As previously indicated, the total mass of radionuclides associated with the 22 boxes previously discussed is about 2.17E+04 grams. (The amount of mass contributed by light elements and fission products such as Cs-137 is negligible, about 16 grams.) Using the dimensions noted above, and modeling a WTF pump as a circular cylinder, each pump occupies a volume of 1,513,555.5 cubic centimeters. Table 1 of WVNS-SD-055 shows that the “normal” specific gravity of “Tank 8D-2 combined waste” is 1.2 grams per cubic centimeter. Using this specific gravity, a pump would need to have slightly over 0.1 cm of contamination (i.e., radioactive material) on its outer surfaces to yield a mass of 2.17E+04 grams. (For reasons noted in the previous paragraph taken from WVNS-SD-055, the inner surfaces should not be significantly contaminated.) Since a significant portion of a WTF pump is not submerged in tank waste, and since a high pressure water spray is used to decontaminate a WTF pump as it is removed from a given tank, it is considered very likely that a given pump would have a mass of radioactive material contamination that is much less than that which corresponds to a layer 0.1 cm thick over its outer surfaces. More importantly, WTF pumps are expected to be contaminated with a distribution of radionuclides that is consistent with high-level waste (HLW). For a given quantity of radionuclides, a HLW distribution would yield a very small fraction (e.g., 0.01) of the actinides that a spent nuclear fuel distribution would yield. Hence, the WTF pumps are considered to provide an essentially negligible source of fissile material.

6.2 Normal Operations and Accident Conditions

Normal operations in the RHWF include handling, size reducing, and repackaging various waste forms. Limited decontamination of waste items with water and/or high pressure nitrogen may be performed. Fissile material in the waste streams shown in Table 1 is insoluble in water and by-and-large is physically and/or chemically fixed/bound to the items that comprise the waste streams. For example, the CPC vessels “received a clear fixative coating.” *Decontamination and Decommissioning of the Chemical Process Cell* provides the following commentary on the “toughness” of this fixative coating: “In addition, it was found that the clear fixative which was used on the vessels had formed an extremely tough crust layer with the floor debris. After a week of minimal progress, it was decided that vacuuming would be delayed until all vessel mounting pads were removed and the fixative crust layer could be broken up.” Other examples of waste items that have radioactive material that would be very difficult to significantly redistribute/reconfigure are the expended ventilation system filters and diatomaceous earth.

Handling and repackaging operations, by their nature, will separate a minuscule amount of radioactive material from the waste items (relative to the total amount of radioactive material associated with the waste items). Size reduction operations will separate from the waste items a very small percentage (e.g., one to three percent) of the total amount of radioactive material present. However, for analyses presented in this document, it is conservatively assumed that 10% of the radioactive material associated with the wastes is separated from the wastes by handling, size reduction, and limited water decontamination activities. Hence, without moderation, many kilograms of fissile material would need to be processed through the RHWF for criticality to become a potentially credible event. (ANSI/ANS-8.1-1983, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, Table 3, shows the single parameter limit for a metal unit of Pu-239 is 5.0 kg, and the single parameter limit for a metal unit of U-235 is 20.1 kg. Given the 10% of radioactive material assumed to separate from waste items, 50 kg Pu-239 Fissile Gram Equivalent (FGE) would need to be in the waste streams. It is not credible that this amount of fissile material would be present in the waste streams.)

There are certain components and locations in the RHWF that conceptually could provide the means for the aggregation/concentration of a non-trivial amount of fissile material in a water moderated environment. These are (1) the storage volume associated with the vacuum system in the Work Cell, (2) the trench in the Work Cell, (3) the drain hub that the Work Cell trench drains into, (4) the Work Cell wash down receiving tank, and (5) the ion exchange column(s). (The batch transfer tank has the same capacity and dimensions as the Work Cell wash down receiving tank, and hence is not included in this list.)

The vacuum system in the Work Cell is a wet/dry vacuum system, but material collected by the system will normally be dry (or possibly somewhat moist in some instances) shavings, chips, fines, and particulate matter generated by size reduction efforts. The storage volume for the vacuum system is a 55 gallon drum liner, as the material collected will normally be processed out of the RHWF in a 55 gallon drum. (If the collected material is considered to be low-level waste, it could be placed in a box used for the disposal of low-level waste.) The fissile material limitations for a 55 gallon drum that are provided in Section 6.3 below apply to the waste container used with the vacuum system. Table 1 of ANSI/ANS-8.1-1983 provides a single parameter limit of 480 grams of Pu-239 for a uniform aqueous solution. This mass is approximately the entire mass of fissile material estimated to be contained in all of the waste streams to be processed through the RHWF. Given the 10% of radioactive material assumed to separate from waste items, 4.8 kg Pu-239 FGE would need to be in the waste streams for there to be the potential for a criticality event. It is expected that the 55 gallon drum liner associated with the vacuum system will be replaced periodically as each liner becomes loaded or approaches the allowed amount of fissile material. Given these facts, it is considered not credible for an inadvertent criticality to occur in the vacuum system.

The Work Cell vacuum system and the exhaust ventilation system that services the Work Cell will collect the vast majority of shavings, chips, fines, and particulate matter generated by handling and size reduction activities. Hence, water washdown of Work Cell SSCs, limited water and/or high pressure nitrogen decontamination of waste items, and relatively small quantities of non-hazardous (in accordance with the Resource Conservation and Recovery Act (RCRA)) liquids that may be present in a few of the incoming waste containers will provide very little fissile material that could enter the Work Cell trench and drain hub, and even less that could enter the Work Cell wash down receiving tank or ion exchange column(s) because of the fine mesh screens in the Work Cell drain hub. (When liquid is detected in a waste container, it will be characterized to facilitate its disposition. Hazardous liquid will not intentionally be directed to the Work Cell wash down receiving tank.) In consideration of these facts, the rationale contained the previous paragraph is deemed to be applicable to the Work Cell trench, drain hub, wash down receiving tank, and ion exchange column(s), and the conclusion is the same, namely, criticality is not credible. Additionally, there are features associated with the trench, drain hub, wash down receiving tank, and ion exchange column(s) that further ensure an inadvertent criticality is not credible. These features provide defense-in-depth, but they are not relied upon for criticality safety in the RHWF. These features are described in the following paragraphs.

The Work Cell trench is approximately 6 inches wide, with a depth of at least 2 inches at the north end. (The trench runs in the north-south direction, with the drain hub at the south end. The slope in the trench is 0.125 inch per foot of trench length.) The maximum wash down water flow rate of 30 gpm will drain efficiently (i.e., without significant "backup") to the wash down receiving tank with over half of the strainer area in the drain hub plugged. Hence, decontamination water containing debris and particulate matter will exist as a "thin sheet" in the trench. A criticality event can not occur with this geometry. Table 1 of ANSI/ANS-8.1-1983 shows that a uniform aqueous solution slab of U-233 must be at least 2.5 cm thick for criticality to occur. (The smallest slab thickness is associated with U-233, as opposed to U-235 or Pu-239. For U-235, the relevant thickness is 4.4 cm.)

Specification 79303-044-02, *Drains and Filter Specifications*, states that the Work Cell drain hub has "maximum outside dimensions" of 22 inches by 31 inches, and is 25.75 inches deep. The drain hub contains a replaceable drain filter and a fixed drain filter. The fixed drain filter has the limiting flow area, approximately 11 inches by 20 inches. However, the filters have the same four layer construction. Section 3.2.4 of Specification 79303-044-02 states the following:

> The screen structure is composed of 4 layers: a 40 thread per inch (TPI) wire mesh, then a 120 TPI mesh, then another 40 TPI mesh, and finally a 16-gauge plate perforated with 1/8th inch holes. These layers are held together by a U-shaped binding made of 16-gauge stainless steel. The total thickness at the U-binder is expected to be approximately 0.35 inches. This filter design shall be used for both the removable filter and the fixed filter. The cartridge allows the removable filter to be brought to the shield window for easy replacement, but the fixed filter remains in the drain hub at all times during normal operation and is not attached to the cartridge.

Hence, only extremely small particulate matter (i.e., particulate matter with a maximum dimension of about 120 microns) will enter the Work Cell wash down receiving tank and ion exchange column(s). Aggregation of debris and particulate matter on the filter(s) will lead to a mass of material that more resembles a "metal unit" with external moderation (during washdown activities) than a "uniform aqueous solution." ANSI/ANS-8.1-1983, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, Table 3, shows the single parameter limit for a metal unit of U-235 is 20.1 kg. (However, this limit is for a "metal unit" that does not have external moderation. With external (water) moderation, less than 20.1 kg of U-235 would be required for criticality, but far more than that estimated to be processed through the RHWF.) If the aggregation of debris and particulate matter on the filter(s) is assessed as a "uniform aqueous solution" (during washdown activities), Table 1 of ANSI/ANS-8.1-1983 shows that a "uniform aqueous solution" slab of U-235 must be at least 4.4 cm thick for criticality to occur. This thickness would indicate significant blockage exists in the filters and/or a very large amount of debris and particulate matter has been allowed to accumulate. This thickness would also indicate that debris and particulate matter are approaching the same level as the bottom of the Work Cell trench (as measured from the top of the removable filter cartridge).

The Work Cell wash down receiving tank is made of stainless steel and is 5 ft in diameter, with a length of 10.66 ft which is oriented horizontally, but slightly sloped to facilitate drainage. The tank has a working capacity of 1,200 gallons, and a total capacity of 1,500 gallons. The tank is vented to the Work Cell. Note 2 on drawing 911-D-023, *Remote Handled Waste Facility Piping & Instrument Diagram Waste Collection & Transfer System*, states that the “liquid level of the tank shall be maintained 3 inches above drainage lines.” This corresponds to approximately 25 gallons of liquid, which reduces the likelihood that fissile material will be concentrated in an aqueous environment (i.e., that fissile material will aggregate in a relatively small but critically meaningful liquid volume (e.g., one to two gallons)). A transfer/recirculation pump will be used to circulate liquids in the tank, which will promote mixing and aid in preventing sludge formation.

Prior to being sent from the RHWF, liquid in the Work Cell wash down receiving tank may occasionally be passed through ion exchange column(s) that will serve the primary purpose of removing radionuclides that produce (high) gamma dose rates. The column(s) are not designed for the purpose of retaining key fissile radionuclides such as U-233, U-235, and Pu-239, and hence very little (i.e., essentially negligible) fissile material will accumulate in the ion exchange column(s).

Liquid transfers from the RHWF Liquid Waste Collection and Transfer System to other facilities or systems at the WVDP must comply with PSR-1, *Requirements for Liquid Transfers of Fissile Material*.

No credible accidents have been identified that are considered to have the potential to redistribute (and aggregate) a significant amount of the limited fissile material associated with the waste streams shown in Table 1.

Normal operations will entail the repackaging of wastes. Fissile mass limits for waste containers that will be used for the repackaging of TRU wastes are addressed below.

6.3 Repackaged Wastes

SDD R02, *System Design Description for Waste Packaging System*, stipulates that only 55 gallon drums or Standard Waste Boxes (SWBs) will be used for packaging TRU wastes. For purposes of this NCSE, a 55 gallon drum is the same as that defined in the preface to WVDP-218, *Process Safety Requirements*: “A cylindrical carbon-steel or stainless-steel container having a nominal capacity of 55 gallons; having a minimum inner diameter that is not less than 22 inches; and having a minimum outer height that is not less than 34 inches (with the lid in place).” Waste containing fissile material (which includes waste designated as TRU waste) shall be packaged and managed in a manner that complies with the requirements given in PSR-6, *Fissile Material Packaging and Storage Requirements*.

7.0 DESIGN FEATURES (PASSIVE AND ACTIVE) AND ADMINISTRATIVELY CONTROLLED LIMITS AND REQUIREMENTS

There are no design features that are relied upon to ensure criticality safety in the RHWF. Certain SSCs in the RHWF have been designed to provide defense-in-depth in preventing a criticality event; however, this NCSE establishes that no passive or active SSCs are required to ensure that a criticality event in the RHWF is not a credible event.

Administrative controls for nuclear criticality safety associated with operations in the Remote Handled Waste Facility will be the same as those applied elsewhere at the WVDP. Transfers of liquids from the RHWF Liquid Waste Collection and Transfer System to other facilities or systems at the WVDP that involve greater than1 gram of fissile material must comply with PSR-1, *Requirements for Liquid Transfers of Fissile Material.* Additionally, wastes containing greater than 1 gram of fissile material shall be packaged and managed in a manner that complies with the requirements given in PSR-6, *Fissile Material Packaging and Storage Requirements.*

8.0 SUMMARY AND CONCLUSIONS

This NCSE establishes that no passive or active SSCs are required to ensure that a criticality event in the RHWF is not a credible event. The analyses demonstrate that for the waste streams proposed to be processed through the RHWF, it is not credible for a criticality event to occur during normal operations or as a result of credible accidents or abnormal operations.

An inadvertent criticality event is not credible because (1) the total amount of fissile material estimated to be present in all waste streams is only marginally greater than the most restrictive single parameter mass limit specified ANSI/ANS-8.1-1983; (2) the fissile material is distributed through a very large volume and mass of waste materials, only a small percentage of which will be in the RHWF at any given time; (3) the fissile material in the waste streams is by-and-large physically and/or chemically fixed/bound to the items that comprise the waste streams; and (4) there are no normal operations or credible accidents that have the potential to accumulate a significant amount of the fissile material in a moderated environment. All areas in the RHWF where fissile materials could be present will remain subcritical under all normal and credible abnormal and accident conditions.

9.0 REFERENCES

American Nuclear Society. ANSI/ANS-8.1-1983. *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*. 1983.

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TABLE 1
WASTE STREAMS TO BE PROCESSED IN THE REMOTE HANDLED WASTE FACILITY[1]

Waste Stream ID #	Description	Anticipated Waste Category	Max. Length (ft)	Max. Width (ft)	Max. Height (ft)	Max. Weight (lbs)	Total WS Weight (lbs)
12	CPC Jumper Boxes	TRU	12.96	6.92	6.96	11,697	43,325
13	CPC Jumper Boxes	LLW	12.96	6.92	6.96	12,193	85,638
14	CPC Dissolver Vessels (includes Boxes 3C-1 and 3C-2)	TRU	19.88	11.79	11.22	35,854	71,708
15	CPC Vessel Boxes	TRU	13.72	8.42	8.96	9,942	15,842
16	CPC Vessel Boxes	LLW	16.58	11.44	11.02	21,119	65,035
17	Vent Filter Boxes	TRU	6.33	7.50	6.0	13,274	296,000
18	Vent Filters in Cement	TRU	11.42	7.42	6.42	53,800	191,300
19	Shield Boxes in CPC-WSA	TRU	12.50	6.50	6.50	9,648	81,883
20	Shielded Boxes with Dry Activated Waste	LLW	12.0	6.0	6.0	10,500	65,000
21	Shielded Resin Tanks	LLW	6.0	6.0	6.0	25,430	254,300
22	Shielded Containers	LLW	2.0 dia.	Cyl.	3.0	1,390	14,300
23	Waste Tank Farm Pumps[2]	LLW	50.0	4.0	4.0	10,000	149,000
24	Head End Cell Closure Wastes	LLW	12.0	6.0	6.0	11,800	47,280

Notes: 1. Table is based on WVNS-IRP-006, *Remote Handled Waste Facility Integrated Run Plan*, and other RHWF design documents. The dimensions shown are for the largest container in a given waste stream (WS). If actual numbers are found to be different from those shown in this table, the results and conclusions in this NCSE remain valid.
2. Mechanical arms from the Waste Tank Farm may be included with WS 23.

TABLE 2
DOUBLE CONTINGENCY ANALYSIS FOR THE RHWF

No.	Description of Action or Abnormal or Accident Event That Could Lead to Criticality	Barriers
1	Any normal activity or credible accident in the RHWF, except repackaging activities	(1) There is a very limited amount of fissile material estimated to be present in the waste streams to be processed in the RHWF (i.e., an amount less than the single parameter limit of 760 grams of U-235 for a uniform aqueous solution per ANSI/ANS-8.1-1983). (2) The fissile material is distributed through a very large volume and mass of waste materials; only a small percentage of which will be in the RHWF at any given time. Hence, geometry and concentration are major barriers to a criticality event. (3) The fissile material in the waste streams is by-and-large physically and/or chemically fixed/bound to the items that comprise the waste streams, and there are no normal operations or credible accidents that are considered to have the potential to redistribute (and aggregate) a significant amount of the fissile material, especially in a (water) moderated environment. This further supports that geometry and concentration are major barriers to a criticality event. The Work Cell vacuum system and the exhaust ventilation system that services the Work Cell will collect the vast majority of shavings, chips, fines, and particulate matter generated by handling and size reduction activities. Hence, water washdown of Work Cell SSCs, limited water and/or high pressure nitrogen decontamination of waste items, and relatively small quantities of non-hazardous liquids that may be present in a few of the waste containers will provide very little fissile material that could enter the Work Cell trench and drain hub, and even less that could enter the Work Cell wash down receiving tank and ion exchange column(s) because of the fine mesh screens in the Work Cell drain hub.

TABLE 2 *(concluded)*
DOUBLE CONTINGENCY ANALYSIS FOR THE RHWF

No.	Description of Action or Abnormal or Accident Event That Could Lead to Criticality	Barriers
2	Repackaging activities (including any short-term “holding” of loaded waste containers in the Load Out/Truck Bay area)	(1) There is a very limited amount of fissile material estimated to be present in the waste streams to be processed in the RHWF (i.e., an amount less than the single parameter limit of 760 grams of U-235 for a uniform aqueous solution per ANSI/ANS-8.1-1983). (2) Human and/or instrument error(s) would need to occur that result in placing much more fissile material in a given waste container than is allowed per fissile loading limitations contained in PSR-6. (3) The fissile material is distributed through a very large volume and mass of waste materials; only a small percentage of which will be in the RHWF at any given time. Additionally, the fissile material in the waste streams is by-and-large physically and/or chemically fixed/bound to the items that comprise the waste streams. Since a given waste container can only contain a very small fraction of the waste items to be processed through the RHWF, geometry and concentration are major barriers. (4) Significant quantities of a moderator (e.g., water) would need to be introduced into a given TRU (more generally, fissile bearing) waste container, which is not allowed by procedure.

TABLE 3

ORIGEN-ARP GENERATED INPUT FILE FOR DECAYING 274.29 CURIES OF CS-137 FOR 6.75 YEARS

```
'This SCALE input file was generated by
'OrigenArp Version 1.00 6-29-2001
#origens
0$$ a11 71 e t
Decay Case
3$$ 21 1 1 0 a16 4 a33 0 e t
35$$ 0 t
54$$ a8 1 e
56$$ a2 7 a6 1 a10 0 a13 1 a14 5 a15 3 a17 2 e
57** 0 e t
Case 1
yyy
60** 0.01 0.03 0.1 0.3 1 3 6.75
61** f1e-015
65$$
'Gram-Atoms  Grams  Curies  Watts-All  Watts-Gamma
3z  1  0  0  1  0  0  3z  3z  6z
 3z  1  0  0
1  0  0  3z  3z  6z
 3z  1  0  0  1  0  0  3z
3z  6z
73$$ 551370
74** 274.29
75$$ 3
t
56$$ 0 0 a10 1 e t
56$$ 0 0 a10 2 e t
56$$ 0 0 a10 3 e t
56$$ 0 0 a10 4 e t
56$$ 0 0 a10 5 e t
56$$ 0 0 a10 6 e t
56$$ 0 0 a10 7 e t
56$$ f0 t
end
#shell
copy ft71f001 C:\OrigenArp\cs.f71
del ft71f001
end
```

TABLE 4
ORIGEN-S OUTPUT FOR DECAYING 274.29 CURIES OF CS-137 FOR 6.75 YEARS

fission products
nuclide radioactivity, curies
basis =yyy

	initial	1E-02 yr	3E-02 yr	0.1 yr	0.3 yr	1.0 yr	3.0 yr	6.8 yr
cs137	2.74E+02	2.74E+02	2.74E+02	2.74E+02	2.72E+02	2.68E+02	2.56E+02	2.35E+02
ba137m	0.00E+00	2.59E+02	2.59E+02	2.58E+02	2.57E+02	2.53E+02	2.42E+02	2.22E+02
total	2.74E+02	5.33E+02	5.33E+02	5.32E+02	5.30E+02	5.21E+02	4.98E+02	4.56E+02

TABLE 5
ACTIVITY IN 22 CPC-WSA BOXES AS OF APRIL 1, 1993

Cs-137	Curies 4-1-93 =	235
Ratioed	Cs-137 Value =	3.41E-05
	SNF Curies	22 Boxes Curies
	Total 1993	on 4-1-93
C-14	1.370E+02	4.673E-03
Fe-55	3.350E+02	1.143E-02
Ni-59	9.930E+01	3.387E-03
Co-60	2.440E+04	8.322E-01
Ni-63	8.450E+03	2.882E-01
Se-79	4.030E+01	1.375E-03
Sr-90	6.370E+06	2.173E+02
Y-90	6.370E+06	2.173E+02
Zr-93	2.460E+02	8.390E-03
Nb-93m	1.930E+02	6.583E-03
Tc-99	1.700E+03	5.798E-02
Ru-106	2.260E+00	7.708E-05
Rh-106	2.260E+00	7.708E-05
Pd-107	1.330E+00	4.536E-05
Sb-125	1.080E+03	3.684E-02
Te-125m	2.490E+02	8.493E-03
Sn-126	4.350E+01	1.484E-03
Sb-126m	4.350E+01	1.484E-03
Sb-126	1.740E+01	5.935E-04
Cs-134	2.620E+03	8.936E-02
Cs-135	1.610E+02	5.491E-03
Cs-137	6.890E+06	2.350E+02
Ba-137m	6.470E+06	2.207E+02
Ce-144	6.750E-02	2.302E-06
Pr-144	6.750E-02	2.302E-06
Pm-147	6.540E+04	2.231E+00
Sm-151	2.050E+05	6.992E+00
Eu-152	3.450E+02	1.177E-02
Eu-154	8.130E+04	2.773E+00
Eu-155	9.900E+03	3.377E-01

TABLE 5 *(concluded)*
ACTIVITY IN 22 CPC-WSA BOXES AS OF APRIL 1, 1993

	SNF Curies	22 Boxes Curies
	Total 1993	on 4-1-93
U-232	1.660E+03	5.662E-02
U-233	2.340E+03	7.981E-02
U-234	1.120E+03	3.820E-02
U-235	2.490E+01	8.493E-04
U-236	7.400E+01	2.524E-03
U-238	2.090E+02	7.128E-03
Np-237	2.630E+01	8.970E-04
Np-239	5.000E+03	1.705E-01
Pu-238	3.670E+05	1.252E+01
Pu-239	9.410E+04	3.210E+00
Pu-240	7.170E+04	2.446E+00
Pu-241	3.540E+06	1.207E+02
Pu-242	9.390E+01	3.203E-03
Am-241	1.090E+05	3.718E+00
Am-242	8.380E+02	2.858E-02
Am-242m	8.430E+02	2.875E-02
Am-243	5.010E+03	1.709E-01
Cm-242	6.850E+02	2.336E-02
Cm-243	2.700E+01	9.209E-04
Cm-244	1.590E+04	5.423E-01
Cm-245	2.420E+00	8.254E-05
Cm-246	3.820E-01	1.303E-05

TABLE 6
ORIGEN-ARP GENERATED INPUT FILE FOR DECAYING ACTIVITY IN 22 CPC-WSA BOXES FOR 11.25 YEARS

```
'This SCALE input file was generated by
'OrigenArp Version 1.00 6-29-2001
#origens
0$$ a11 71 e t
Decay Case
3$$ 21 1 1 27 a16 4 a33 18 e t
35$$ 0 t
54$$ a8 1 e
56$$ a2 8 a6 1 a10 0 a13 50 a14 5 a15 3 a17 2 e
57** 0 e t
Case 1
SPENTNUCLEARFUEL
60** 0.01 0.03 0.1 0.3 1 3 8 11.25
61** f1e-015
65$$
'Gram-Atoms  Grams  Curies  Watts-All  Watts-Gamma
3z  1  0  0  1  0  0  3z  3z  6z
 3z  1  0  0
1  0  0  3z  3z  6z
 3z  1  0  0  1  0  0  3z
3z  6z
81$$ 2 0 26 1 e
82$$ 2 2 2 2 2 2 2 2 e
83**
1.E+7    8.E+6    6.5E+6    5.E+6    4.E+6    3.E+6
2.5E+6    2.E+6    1.66E+6   1.33E+6   1.E+6    8.E+5
6.E+5    4.E+5    3.E+5    2.E+5    1.E+5    5.E+4
1.E+4    e
84**
2.E+7    6.434E+6   3.E+6    1.85E+6   1.4E+6
9.E+5    4.E+5    1.E+5    1.7E+4    3.E+3    5.5E+2
1.E+2    3.E+1    1.E+1    3.04999E+0  1.77E+0
1.29999E+0  1.12999E+0  1.E+0    8.E-1    4.E-1
3.25E-1   2.25E-1   9.999985E-2 5.E-2    3.E-2
9.999998E-3 1.E-5 e
73$$ 280590 270600 280630 340790 380900 390900 400930 410931 430990
441060 451060 461070 511250 521251 501260 511261 511260 551340 551350
551370 561371 581440 591440 611470 621510 631520 631540 631550 922320
922330 922340 922350 922360 922380 932370 932390 942380 942390 942400
942410 942420 952410 952420 952421 952430 962420 962430 962440 962450
962460
```

TABLE 6 *(concluded)*
ORIGEN-ARP GENERATED INPUT FILE FOR DECAYING ACTIVITY IN 22 CPC-WSA BOXES FOR 11.25 YEARS

```
74** 0.003387 0.8322 0.2882 0.001375 217.3 217.3 0.00839 0.006583
0.05798 7.708e-005 7.708e-005 4.536e-005 0.03684 0.008493 0.001484
0.001484 0.0005935 0.08936 0.005491 235 220.7 2.302e-006 2.302e-006
2.231 6.992 0.01177 2.773 0.3377 0.05662 0.07981 0.0382 0.0008493
0.002524 0.007128 0.000897 0.1705 12.52 3.21 2.446 120.7 0.003203 3.718
0.02858 0.02875 0.1709 0.02336 0.0009209 0.5423 8.254e-005 1.303e-005
75$$ 1 1 1 1 3 3 1 1 1 1 1 1 3 3 3 3 3 1 1 3 3 1 1 1 1 1 1 1 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
t
Case 1 Time Step 1
Case 1 Time Step 2
Case 1 Time Step 3
Case 1 Time Step 4
Case 1 Time Step 5
Case 1 Time Step 6
Case 1 Time Step 7
Case 1 Time Step 8
56$$ 0 0 a10 1 e t
56$$ 0 0 a10 2 e t
56$$ 0 0 a10 3 e t
56$$ 0 0 a10 4 e t
56$$ 0 0 a10 5 e t
56$$ 0 0 a10 6 e t
56$$ 0 0 a10 7 e t
56$$ 0 0 a10 8 e t
56$$ f0 t
end
#shell
copy ft71f001 C:\OrigenArp\22cpc1.f71
del ft71f001
end
```

TABLE 7
ORIGEN-S OUTPUT SHOWING ACTINIDES IN GRAMS FROM DECAYING ACTIVITY IN 22 CPC-WSA BOXES FOR 11.25 YEARS

nuclide concentrations, grams
basis =SPENTNUCLEARFUEL

	initial	1E-02 yr	3E-02 yr	0.1 yr	0.3 yr	1.0 yr	3.0 yr	8.0 yr	11.3 yr
he 4	0.00E+00	1.77E-06	5.31E-06	1.77E-05	5.31E-05	1.78E-04	5.35E-04	1.44E-03	2.03E-03
pb208	0.00E+00	5.15E-11	1.57E-09	3.09E-08	3.35E-07	3.61E-06	2.64E-05	1.19E-04	1.86E-04
pb212	0.00E+00	2.99E-11	2.55E-10	1.24E-09	4.20E-09	1.23E-08	2.66E-08	3.64E-08	3.68E-08
bi212	0.00E+00	2.84E-12	2.42E-11	1.18E-10	3.98E-10	1.17E-09	2.52E-09	3.45E-09	3.49E-09
ra224	0.00E+00	3.58E-10	2.23E-09	1.08E-08	3.66E-08	1.08E-07	2.32E-07	3.18E-07	3.21E-07
th228	0.00E+00	2.50E-07	7.46E-07	2.46E-06	7.10E-06	2.09E-05	4.50E-05	6.17E-05	6.23E-05
th229	0.00E+00	3.54E-07	1.06E-06	3.54E-06	1.06E-05	3.54E-05	1.06E-04	2.83E-04	3.98E-04
th230	0.00E+00	1.70E-07	5.11E-07	1.70E-06	5.11E-06	1.70E-05	5.12E-05	1.37E-04	1.93E-04
th231	0.00E+00	1.45E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09	1.60E-09
th232	0.00E+00	1.13E-08	3.40E-08	1.13E-07	3.40E-07	1.13E-06	3.41E-06	9.08E-06	1.28E-05
th234	0.00E+00	3.07E-08	8.32E-08	2.00E-07	2.95E-07	3.08E-07	3.08E-07	3.08E-07	3.08E-07
pa231	0.00E+00	2.35E-09	9.81E-09	3.80E-08	1.16E-07	3.83E-07	1.15E-06	3.05E-06	4.29E-06
pa233	0.00E+00	3.87E-09	1.06E-08	2.63E-08	4.06E-08	4.33E-08	4.34E-08	4.37E-08	4.40E-08
pa234m	0.00E+00	1.03E-12	2.80E-12	6.75E-12	9.93E-12	1.04E-11	1.04E-11	1.04E-11	1.04E-11
pa234	0.00E+00	4.62E-13	1.25E-12	3.01E-12	4.44E-12	4.64E-12	4.63E-12	4.63E-12	4.63E-12
u232	2.56E-03	2.56E-03	2.56E-03	2.56E-03	2.56E-03	2.54E-03	2.49E-03	2.37E-03	2.29E-03
u233	8.28E+00	8.28E+00	8.28E+00	8.28E+00	8.28E+00	8.28E+00	8.28E+00	8.28E+00	8.28E+00
u234	6.14E+00	6.14E+00	6.14E+00	6.14E+00	6.14E+00	6.15E+00	6.16E+00	6.18E+00	6.20E+00
u235	3.93E+02	3.93E+02	3.93E+02	3.93E+02	3.93E+02	3.93E+02	3.93E+02	3.93E+02	3.93E+02
u236	3.90E+01	3.90E+01	3.90E+01	3.90E+01	3.90E+01	3.90E+01	3.90E+01	3.90E+01	3.90E+01
u237	0.00E+00	1.10E-08	2.38E-08	3.44E-08	3.49E-08	3.37E-08	3.06E-08	2.40E-08	2.05E-08
u238	2.12E+04	2.12E+04	2.12E+04	2.12E+04	2.12E+04	2.12E+04	2.12E+04	2.12E+04	2.12E+04

TABLE 7 *(concluded)*

ORIGEN-S OUTPUT SHOWING ACTINIDES IN GRAMS FROM DECAYING ACTIVITY IN 22 CPC-WSA BOXES FOR 11.25 YEARS

	initial	1E-02 yr	3E-02 yr	0.1 yr	0.3 yr	1.0 yr	3.0 yr	8.0 yr	11.3 yr
np237	1.27E+00	1.27E+00	1.27E+00	1.27E+00	1.27E+00	1.27E+00	1.28E+00	1.29E+00	1.30E+00
np238	0.00E+00	3.48E-10	4.85E-10	4.99E-10	4.98E-10	4.97E-10	4.92E-10	4.80E-10	4.72E-10
np239	7.35E-07	7.36E-07	7.36E-07	7.37E-07	7.36E-07	7.36E-07	7.36E-07	7.36E-07	7.36E-07
pu238	7.31E-01	7.31E-01	7.31E-01	7.30E-01	7.29E-01	7.25E-01	7.14E-01	6.86E-01	6.69E-01
pu239	5.17E+01	5.17E+01	5.17E+01	5.17E+01	5.17E+01	5.17E+01	5.17E+01	5.17E+01	5.17E+01
pu240	1.08E+01	1.08E+01	1.08E+01	1.08E+01	1.08E+01	1.08E+01	1.08E+01	1.08E+01	1.08E+01
pu241	1.17E+00	1.17E+00	1.17E+00	1.16E+00	1.15E+00	1.11E+00	1.01E+00	7.93E-01	6.78E-01
pu242	8.10E-01	8.10E-01	8.10E-01	8.10E-01	8.10E-01	8.10E-01	8.10E-01	8.10E-01	8.10E-01
am241	1.08E+00	1.08E+00	1.09E+00	1.09E+00	1.10E+00	1.14E+00	1.24E+00	1.44E+00	1.55E+00
am242m	2.74E-03	2.74E-03	2.74E-03	2.74E-03	2.74E-03	2.73E-03	2.70E-03	2.64E-03	2.60E-03
am242	3.53E-08	3.54E-08	3.54E-08	3.54E-08	3.53E-08	3.52E-08	3.49E-08	3.40E-08	3.35E-08
am243	8.56E-01	8.56E-01	8.56E-01	8.56E-01	8.56E-01	8.56E-01	8.56E-01	8.55E-01	8.55E-01
cm242	7.05E-06	7.05E-06	7.06E-06	7.06E-06	7.08E-06	7.10E-06	7.05E-06	6.87E-06	6.78E-06
cm243	1.78E-05	1.78E-05	1.78E-05	1.78E-05	1.77E-05	1.74E-05	1.66E-05	1.47E-05	1.36E-05
cm244	6.70E-03	6.69E-03	6.69E-03	6.67E-03	6.62E-03	6.45E-03	5.97E-03	4.93E-03	4.35E-03
cm245	4.81E-04	4.81E-04	4.81E-04	4.81E-04	4.81E-04	4.80E-04	4.80E-04	4.80E-04	4.80E-04
cm246	4.24E-05	4.24E-05	4.24E-05	4.24E-05	4.24E-05	4.24E-05	4.24E-05	4.24E-05	4.23E-05
total	2.17E+04	2.17E+04	2.17E+04	2.17E+04	2.17E+04	2.17E+04	2.17E+04	2.17E+04	2.17E+04